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THE AVERAGE IGNEOUS ROCK

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The chemical composition of the average igneous or crystalline rock of the earth's crust is of sufficient interest to geologists and petrographers to have elicited several attempts at compiling average analyses. Clarke[1] summarizes the three most important averages of igneous rock analyses—those by Clarke, by Harker, and by Washington. These averages agree fairly well, showing very small differences in the amounts of the various oxides, and there is little to be said of the relative merits of the three determinations.

One question, however, has been repeatedly raised, i.e.: Does the average of all igneous rock analyses represent with any degree of certainty the actual average of the igneous rocks of the earth's shell? Obviously, if the average analyses of Clarke, Harker, and Washington are to represent correctly the composition of the igneous rocks of the earth's crust, it is necessary that the samples of the various types of igneous rock be proportional to the amounts of these several types in the earth's crust. If not, these average analyses are misleading.

In the course of certain investigations in the Metamorphic Laboratory at the University of Wisconsin, the writer has attempted to check Clarke's average igneous rock by comparing it with the composition of the sediments, and the results obtained are thought to be of sufficient interest to warrant their presentation here.

If we are correct in the assumption that the oxides of the bases and the silica of the sediments have as their ultimate source the igneous rocks, then a properly weighted average of the sediments (excluding water and carbon dioxide) would represent very closely the average composition of the igneous rocks from which these sediments were derived. Certain discrepancies are to be expected owing to the segregation of certain constituents, such as the mineral matter in the sea and certain mineral deposits not included in the sedimentary rocks. The solution of this problem was attempted by the writer and the results published in this journal.[1]

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[1] F. W. Clarke, "Data of Geochemistry," *U.S. Geol. Survey*, *Bull. 491*, 1911.

The former problem may be briefly stated as follows: given, the average composition of the igneous rocks and of the shales, sandstones, and limestones; to find the relative abundance of these three important types of sediments. The present problem, while somewhat similar, differs materially, and may be stated as follows: assuming that the average igneous rock may be closely approximated in composition by some combination of average granite and average basalt, what ratio of granite to basalt best explains the composition of the sediments as expressed by average analyses of the shales, sandstones, and limestones, respectively; and simultaneously with this solution, what ratio of shale, sandstone, and limestone would result from the redistribution of this combination of granite and basalt? The above might be stated in the form of an equation as follows:

> x granite$+y$ basalt$=a$ shale$+b$ sandstone$+c$ limestone, given average analyses of granite, basalt, shale, sandstone, and limestone to solve for x, y, a, b, c.

Note that no assumption is made as to the relative abundance of shale, sandstone, and limestone, and that the solution of the problem is based in no way on the results previously obtained[2] *or on any assumption as to the average composition of the igneous rocks.* The data used in this problem are given in Table I. The average granite and average basalt, columns 1 and 2, are those compiled by Dr. Daly.[3] The average analyses of the shales, sandstones, and limestones, respectively, are those compiled by Clarke.[4] Since the water and carbon dioxide of the sediments are for the most part derived from the hydrosphere and atmosphere, it is necessary in this problem to recalculate the analyses of the sediments, excluding these constituents. The analyses of the igneous rocks are recalculated on a water-free basis. Since the problem does not permit of a rigorous solution, graphic methods have been used which permit of viewing in perspective, as it were, the various relations and conceptions involved.

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[1] W. J. Mead, "Redistribution of Elements in the Formation of Sedimentary Rocks," *Jour. Geol.*, XV (1907), 238–56.

[2] W. J. Mead, *op. cit.*

[3] R. A. Daly, "Average Chemical Compositions of Igneous-Rock Types," *Proc. Amer. Acad. Arts and Sciences*, XLV (1910), 211–40.

[4] F. W. Clarke, *op. cit.*, p. 28.

TABLE I

	1	2	3	4	5	6	7	8
SiO_2	70.47	49.65	58.38	64.00	78.66	83.95	5.19	9.02
Al_2O_3	14.90	16.13	15.47	16.94	4.78	5.10	.81	1.41
Fe_2O_3	1.63	5.47	4.03	4.42	1.08	1.15	.54	.94
FeO	1.68	6.45	2.46	2.69	.30	.32		
MgO	.98	6.14	2.45	2.68	1.17	1.25	7.90	13.74
CaO	2.17	9.07	3.12	3.42	5.52	5.90	42.61	74.10
Na_2O	3.31	3.24	1.31	1.43	.45	.48	.05	.09
K_2O	4.10	1.66	3.25	3.56	1.32	1.41	.33	.57
TiO^1	.39	1.41	.65	.71	.25	.27	.06	.10
P_2O_5	.24	.48	.17	.19	.08	.085	.04	.07
Totals	99.87	99.70	91.29	100.04	93.61	99.915	57.53	100.04
Fe	2.45	8.86	....	5.19	....	1.055	....	.66

1. Average granite.
2. Average basalt.
3. Average shale.
4. Average shale recalculated to 100 per cent, omitting H_2O and CO_2.
5. Average sandstone.
6. Average sandstone recalculated to 100 per cent, omitting H_2O and CO_2.
7. Average limestone.
8. Average limestone recalculated to 100 per cent, omitting H_2O and CO_2.

Trilinear co-ordinates are used in Fig. 1; the triangle labeled in the corners "Shale," "Limestone," and "Sandstone," respectively, serves as a base on which ratios of these three components may be indicated by points, and a series of ratios represented by lines. The algebraic sum of the perpendicular distances from any point inside or outside of the triangle to the three sides of the triangle or their extensions equals the altitude of the triangle, considering distances toward the opposite apex as positive, and distances away from the opposite apex as negative. *Any point on the dotted line labeled "SiO_2, Gr." represents in parts per hundred the ratio in which shale, sandstone, and limestone may be combined to yield the same amount of silica as the average granite.* This line is obtained by finding the proportion in which sandstone and limestone combine to yield the same percentage of silica as the average granite, and also the proportion in which shale and limestone combine to the same end. These points platted on the sides of the triangle determine the line. In a similar manner lines are drawn for the various oxides[1] for both the average granite and the

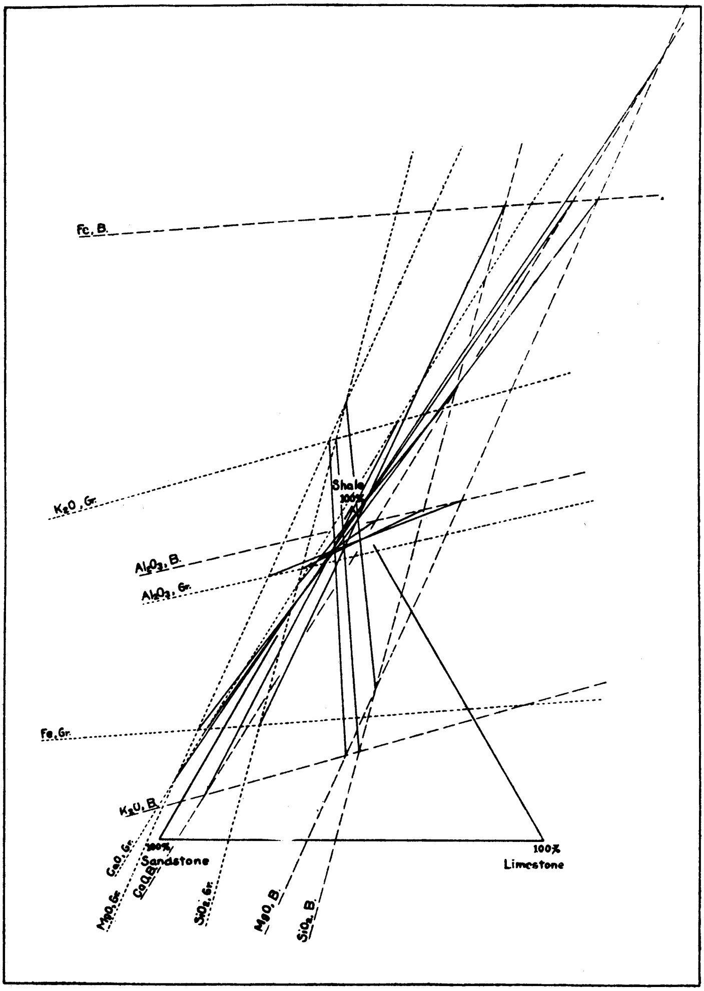

FIG. 1.—Graphical expression of the relations of any combination of granite and basalt and the ratios of sediments derived from them.

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[1] Iron is calculated as total Fe, the oxides not being considered separately.

average basalt. The very low soda content of the sediments due to the segregation of that constituent in the sea causes the soda line to fall too far outside the triangle to be shown. If the sediments were derived from the average granite, the lines of the several oxides would come very close to intersecting at a point, but since this is not true, the lines for granite are widely distributed and their intersections fall over a wide area. This is likewise true of the basalt lines.

The point of intersection of the dotted silica and alumina lines indicates the ratio of shale, sandstone, and limestone containing the same amount of silica and alumina as the average granite. Similarly the intersection of the broken silica and alumina lines indicates the ratio of shale, sandstone, and limestone containing the same amount of silica and alumina as the average basalt. *The line connecting these two points of intersection is the locus of the intersections of the silica and alumina lines for any combination of granite and basalt.* In this manner lines connecting similar intersections of granite und basalt lines have been drawn. *If the sediments were derived from some combination of granite and basalt, these lines connecting intersections should intersect at a common point.* However, because of the nature of the data, we may expect at best that these lines will intersect within a small area. An examination of the diagram, Fig. 1, shows that this is exactly what happens; i.e., there is a distinct tendency for these lines to converge and intersect within a limited area. If the lines connecting intersections crossed each other at a common point, the ratio of granite to basalt would be measured by the ratio of the distances from the point of intersection to the "granite" and "basalt" ends of the lines respectively.

In order to determine whether there is any tendency toward the expression of a definite ratio of granite to basalt by the grouping of the points of intersection on each of the several connecting lines, these lines have been transferred from Fig. 1 to Fig. 2, where by means of a proportional triangle each line is automatically divided into ten equal parts. The points of intersection of any line with the other lines are marked by short lines crossing the line considered. Inspection of the proportional triangle on which these lines have been placed shows that there is marked uniformity in the ratio of granite to basalt, as expressed by the positions of intersection on these several lines. The average of the ratios expressed by the points of intersection on each line has been indicated by a large dot near the line, and the positions of these dots on the scale of the proportional triangle show a distinct concordance. By averaging the ratios expressed by the dots on the several lines, the average ratio of granite to basalt is found to be 65 parts granite to 35 parts basalt, i.e., this is the proportion of granite to basalt which may be most closely approximated by some combination of derived sediments represented by their average analyses here employed.

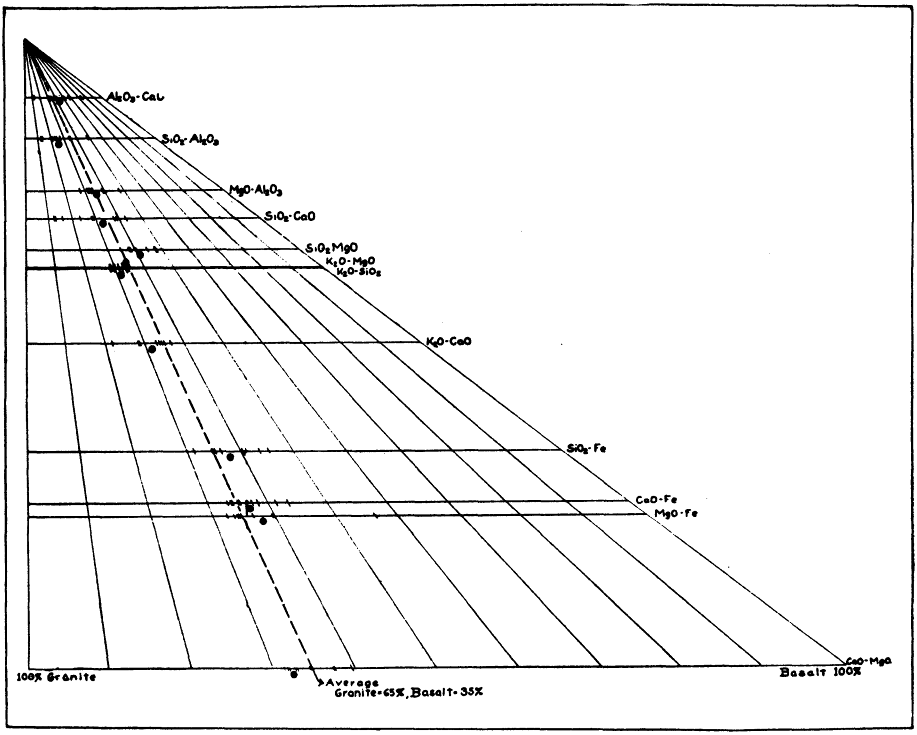

FIG. 2.—Proportional triangle used as a scale on which to measure the granite-basalt ratios expressed by the position of intersections on the full black lines in Fig. 1.

This solution assumes that the average analyses of granite, basalts, shales, limestones, and sandstones used are approximately correct, and that the average igneous rock may be represented by some combination of granite and basalt. So far as these assumptions are not true, solution fails, but the fact that the graphical method admits of selecting a definite ratio of granite and basalt and that this ratio yields an average so similar to the average for the igneous rock obtained by Clarke and others seems to indicate that the data and assumptions are not in serious error.

In Table II, column 1 is the average analysis obtained by combining the average granite and the average basalt in this ratio. For purposes of comparison the average analyses of igneous rocks obtained by Clarke, Harker, and Washington are placed in parallel columns.

TABLE II

	1	2*	3	4	5*	6*
SiO_2..............	62.18	61.82	+1.36	+2.2	60.76	58.96
Al_2O_3.............	15.35	15.51	− .16	−1.03	15.87	15.99
Fe_2O_3.............	2.97	2.67	+ .20	+ 7.5	4.92	3.37
FeO..............	3.35	3.45	− .10	− 2.9	2.78	3.93
MgO..............	2.79	4.02	−1.23	−30.5	3.82	3.89
CaO..............	4.58	4.96	− .38	− 8.45	4.97	5.28
Na_2O..............	3.28	3.51	− .23	− 6.5	3.28	3.96
K_2O..............	3.24	3.04	+ .20	+ 6.6	2.85	3.20

* F. W. Clarke, *op. cit.*, p. 25.

1. Average granite and average basalt, combined in ratio of 65 to 35.
2. Clarke's average igneous rock.
3. Differences between 1 and 2, on basis of total rock.
4. Differences between 1 and 2, in percentage for each constituent.
5. Harker's average igneous rock.
6. Washington's average igneous rock.

The differences between column 1 and the three average analyses of igneous rocks are small. The differences between column 1 and Clarke's average igneous rock are expressed in terms of the entire rock and in percentage of each constituent in columns 3 and 4 respectively. The most striking result of the comparison is the marked similarity between the combined granite and basalt and the average analyses. The greatest differences are for silica and magnesia, the combination of granite and basalt being slightly more acidic than the other averages.

The most important conclusion is that the average analyses of Clarke, Harker, and Washington are closely checked by this method, and that of the three analyses Clarke's average is most closely approximated. The nature of the data obviously does not permit of drawing any definite conclusions as to the cause of the slight differences between Clarke's averages and the averages here obtained.

The greatest difference occurs for MgO, the combined granite basalt showing 30.5 per cent less MgO than Clarke's average. This difference is so much greater than for any of the other oxides that it may be of significance. It is possible that igneous rocks collected largely for petrographic purposes would include the unusual and interesting alkaline and ultra-basic types, the syenites, peridotites, etc., in an amount out of proportion to their abundance as compared with the more common granite and basalt types. The alkalies, lime, silica, and alumina would not be materially affected by this, as the alkaline rocks would offset the basic varieties, but the range of MgO content being much greater (varying from 1 per cent or less in the alkaline rocks to 30–40 per cent in the peridotites), this oxide would tend to be increased by the inclusion of an excess of the less common rocks.

Ratio of shale, sandstone, and limestone.—The foregoing solution, while yielding rather definitely the ratio of granite and basalt best explaining the composition of the sediments, simultaneously yields the ratio of shale, sandstone, and limestone resulting from the redistribution of this hypothetical average igneous rock. In Fig. 3 the lines for the several oxides were obtained by drawing lines parallel and between the granite and basalt lines on Fig. 1, at distances representing the 65–35 ratio. These lines in Fig. 3 intersect within a small area and a point at the center of this area expresses a ratio of 88 parts shale, 9 parts sandstone, and 3 parts limestone. Since water and carbon dioxide were excluded from the analyses of the sediments in obtaining these ratios, it is necessary to recalculate to include these constituents, which gives 87 parts shale, 8 parts sandstone, and 5 parts limestone. This ratio differs from the ratio of 80:11:9 previously obtained by the writer,[1] by showing more shale, less sandstone, and less limestone, but in a general way is similar in showing the great predominance of shale over the other two sediments.

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[1] W. J. Mead, *op. cit.*

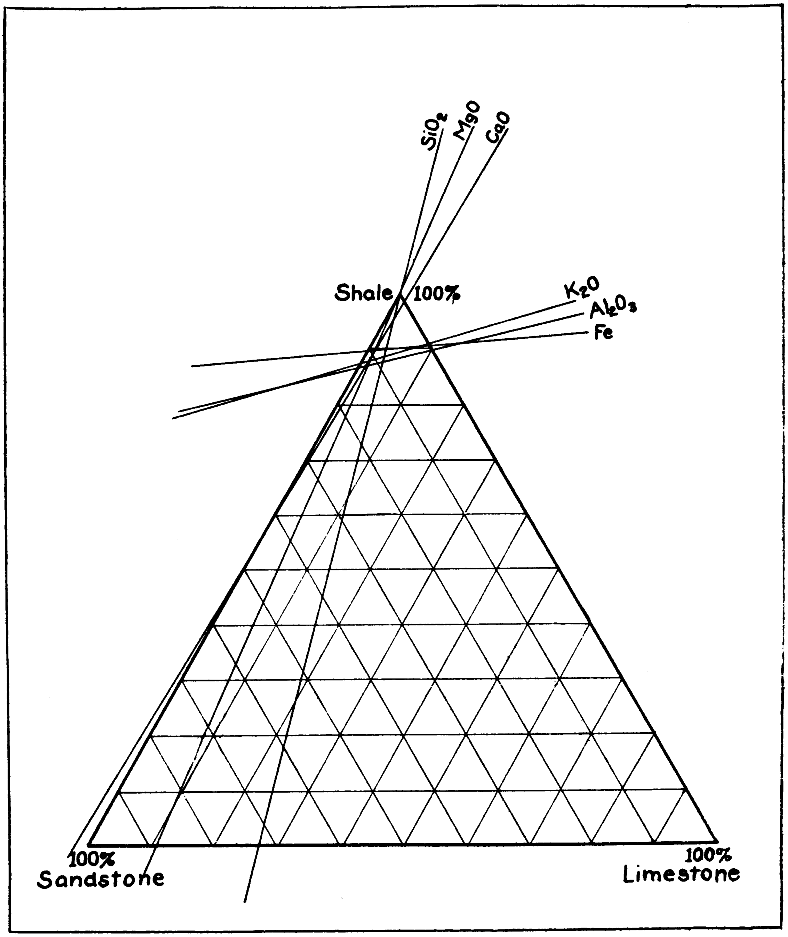

FIG. 3.—The lines on the triangle show for each constituent the proportions in which the three sediments combine to yield the same amount of that constituent as the combination of 65 parts granite and 35 parts basalt. Compare with Fig. 4.

A further comparison of the combined granite and basalt with Clarke's average igneous rock is afforded by comparing Fig. 4 (which represents for Clarke's average exactly what Fig. 3 represents for the combined granite and basalt) with Fig. 3. The lines in Fig. 3 intersect within a much smaller area than in Fig. 4, which is simply another way of expressing the closer accordance of the granite basalt average with the sediments as compared with Clarke's.

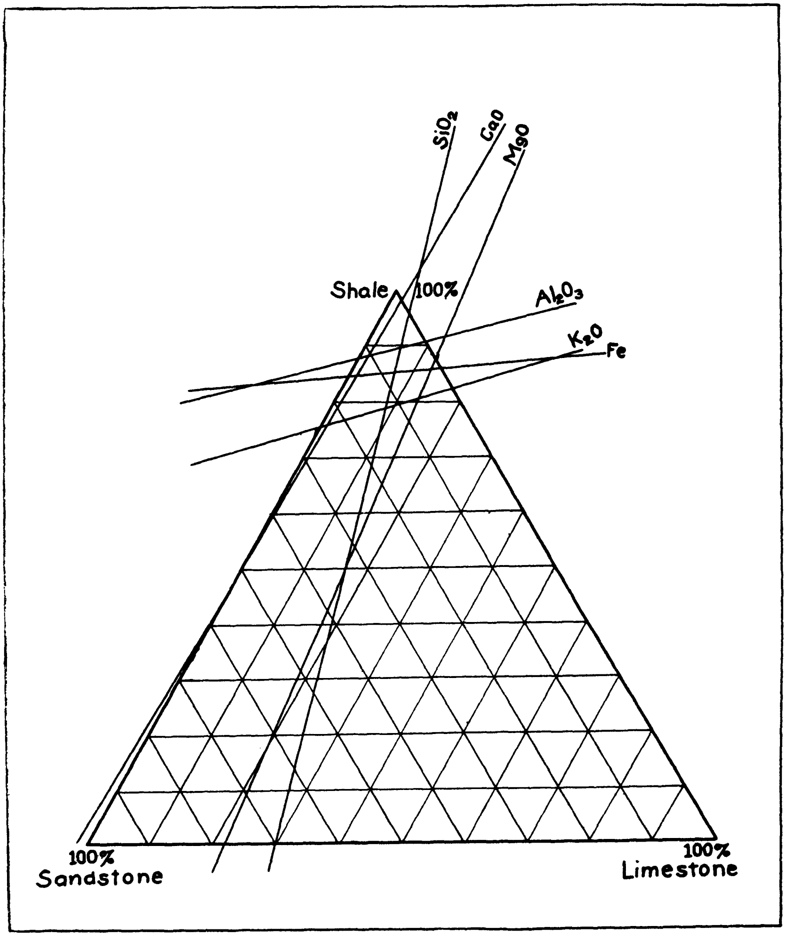

FIG. 4.—The lines on the triangle show for each constituent the proportions in which the three sediments combine to yield the same amount of that constituent as Clarke's average igneous rock. Compare with Fig. 3.